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OF AGRICULTURE AND APPLIED SCIENCE

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Gentlemen:

We are pleased to transmit this Semi-Annual Status Report covering the period September 1, 1964 to February 28, 1965 on NASA Grant NsG-692/17-01-005.

The reports included are in the following order:

Project Title	Principal Investigator	Department
1. The Measurement of Lunar Radiation	E. Brock Dale	Physics
2. The Effect of Gravitational Fields on Enzymatic Reactions Occurring in Inhomogeneous Systems	R. K. Burkhard	Biochemistry
3. Analytic Studies in the Learning and Memory of Skilled Performance	Merrill Noble	Psychology
4. Optimization of Space System Design	G. F. Schrader	Industrial Engineering
5. Ultraviolet Communication	Charles Mandeville	Physics
6. Search for the Dirac Monopole	Robert Katz	Physics
7. Statistical Radar Echo Analysis and Simulation and Its Applications to Planetary Return	H. S. Hayre	Electrical Engineering
8. Determination of Optimum Nozzle Contours for the Expansion of Dissociated Gases by Methods of the Variational Calculus	James M. Bowyer	Mechanical Engineering

We will very much appreciate any comments or suggestions you wish to send us regarding this research.

Sincerely yours,

RESEARCH COORDINATING COUNCIL

John L. Brown, Chairman
Dean, Graduate School

William Bevan, Vice President
Kansas State University

Glenn H. Beck, Dean and Director
Agricultural Experiment Station

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Leland S. Hobson

Leland S. Hobson, Secretary
Director, Engineering Experiment Station

SEMI-ANNUAL STATUS REPORT

to the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Ref: Research Grant NsG - 692 / 17 - 01 - 005

Period - September 1, 1964 to February 28, 1965

from

KANSAS STATE UNIVERSITY
Manhattan, Kansas

Kansas State University
Research Coordinating Council
John L. Brown, Chairman

"THE MEASUREMENT OF LUNAR RADIATION"

by

E. Brock Dale

NASA Grant NsG-692

The first six months have been occupied in the design and construction of an infrared detector and photometer for the wavelength range 9-14 microns, and in adapting the telescope for lunar scanning.

The detectors are mercury-doped germanium wafers on Kovar mounts which can be screwed onto the cold finger of a double dewar cooled with hydrogen or helium. The detector is mounted at the focus of the 18 1/2-inch Cassegranian telescope, behind a rotary shutter and an optical system so disposed that the detector sees alternately a point on the lunar surface and empty space. The interruption frequency of the shutter is 400/sec.

The signal from the detector goes through a stage of preamplification and then to a P.A.R. Model J-5 lock-in amplifier, and the d.c. output is displayed on a pen-type recorder. We expect eventually to add a complementary z-axis oscilloscope display which can be photographed as a visual aid to interpretation of the data.

The declination drive of the telescope has been modified to allow scanning back and forth at constant right ascension. The orbital motion of the moon then carries it past the telescope at approximately half a degree per hour, causing a given point on the moon's image to traverse the telescope's six-second circle of confusion (at ten microns) in about twelve seconds. The fraction of the moon that can be traversed in a given declination scan is limited in practice by the maximum amplifier bandwidth usable with the detector, and has not yet been determined. We are limited geometrically to about half the moon's diameter, however.

Our first detectors were made by heating germanium for 150 hours at 400°C in an atmosphere of mercury vapor at about atmospheric pressure. It was found that the mercury had not diffused to sufficient depth. New wafers have been diffused for 250 hours at 800°C. The infrared transmission of these wafers at ten microns is less than two per cent, indicating that an adequate amount of mercury has been introduced. The penetration depth appears to be less than one micron, however.

We have been offered a piece of melt-doped Ge(Hg) by the Texas Instruments Corporation. As soon as the material arrives it will be incorporated into our detector. We expect to make the first test scans of the moon in May, 1965.

Signed E. Burchard Dels

Date April 15 1965

Semi-annual Report

For

NASA Grant NsG-692

prepared by

R. K. Burkhard, Principal Investigator

April 5, 1965

A study has been undertaken to determine the effect that centrifugation and, hence, an increase in gravitational field, has upon the velocity of enzymatic reactions occurring in inhomogeneous systems.

The first system selected for study involved the enzymatic reduction of neotetrazolium chloride by an enzyme system in heart mitochondria which can use succinate as a substrate. An assay procedure for this type of enzymatic activity was developed, and using this procedure it was found that centrifugation markedly increases the extent of reduction of the neotetrazolium chloride. Further experimentation indicates that this increase is due to concentration of enzyme rather than temperature or streaming effects.

The second system selected for study and currently under study involves the enzymatic hydrolysis of sucrose by invertase. This system is essentially homogeneous and is expected to yield different results than those obtained with the first system.

The significance of the results obtained to date is that they lead to the suggestion that processes in living cells, which certainly are inhomogeneous systems, should be influenced by a change in gravitational field.

G-1082: First Semi-annual report

During the first six months of this grant the following things were accomplished:

(1) An Iconix three field tachistoscope was ordered, received, checked out, and put in working order.

(2) A review of the literature on pattern vision in the peripheral retina was undertaken. On the basis of this review, an equation predicting the order of recognition of various forms was derived and tested in a pilot experiment. Basically, the equation takes the size of the ratio of inscribed to circumscribed circles as a predictor. The smaller the ratio, the less discriminable the form. Thus, regular figures having few sides should be more recognizable than those having many sides.

(3) The pilot experiment used ten subjects, who were simply required to guess which one of five regular forms was presented. The forms were presented to the right eye about 4.75° temporal to the fovea, in the horizontal meridian. Exposure time was 50 msec; illumination level was set for each subject to the level at which he could just see that something had been presented. Results were as predicted.

Signed.

Merrill E. Noble

Merrill E. Noble
Co-principal Investigator

Walter F. Daves

Walter F. Daves
Co-principal Investigator

TO: Research Coordinating Council
Kansas State University

February 25, 1965

FROM: G. F. Schrader
Department of Industrial Engineering

Progress Report-- NASA Grant No. NSG-692

Title: Optimization of Space System Design

Dr. G. F. Schrader, Principal Investigator

The work accomplished and the progress made since September 1, 1964 to the date of report, and the problems under investigation are summarized as follows:

1. The discrete version of maximum principle was applied to obtain solutions for the optimum stage-weight distribution problems of a multistage rocket vehicles. Three problems were considered. The first problem treats the structure ratio as a constant in each stage, though it may differ stage by stage. The second problem considers the variations in structural factors with stage weight. The third problem obtains the optimum weight distribution which minimized hardware weight. A paper (ASME paper No. 64-WA/AV-5, "Optimization of Step Rockets by the Discrete Maximum Principle," by L. T. Fan, C. L. Hwang, and C. S. Wang) reporting these results was presented at the Aviation and Space Division, the Winter Annual Meeting of ASME on December 1, 1964 in New York, New York, and will be published in the Journal of Engineering for Industry, Transactions of ASME.

2. In aerospace activities, transportation type problems find a variety of applications particularly with respect to logistics in both space vehicle and ground support system allocation. A procedure for applying the discrete maximum principle to multidepot transportation problems with the linear objective (cost) function is studied. The results were presented in a paper entitled "The Discrete Maximum Principle Solutions of Multidepot Transportation Problems with the Linear Cost Function" by G. F. Schrader, C. L. Hwang, L. S. Fan and L. T. Fan. It was submitted to the Journal of Production Research for publication in February 1965.

   The application of the maximum principle to multidepot transportation problems with non-linear objective (cost) function is being studied. A paper presenting the results is under preparation and it will be submitted to the AIAA Journal for publications.

3. The continuous version of the maximum principle applied to optimization of chemical reactions in a plug flow tubular reactor has been studied. Several cases of first and second order reversible or irreversible reaction have been investigated. For each case the relationship between the optimal temperature profile along the length of the reactor and the optimal holding time was derived. A paper is under preparation for presenting the results.

4. Application of dynamic programming and the discrete as well as the continuous version of maximum principle to the problems of the reliability of aerospace system is currently under study.

5. The application of the maximum principle to optimal control of simple stochastic processes in both discrete and continuous cases is currently under investigation as concerns application to a variety of aerospace systems.

Semi-Annual Report of the Work

of

NASA Grant NsG-692

Experiments with Ultraviolet Light

Principal Investigator: C. E. Mandeville

Kansas State University

Manhattan, Kansas

10 April 1965

A period of time has been required to partially equip a laboratory and order certain materials and equipment necessary to conducting the work. The initial investigations have concerned a novel means of generating ultraviolet light. A little known effect has been employed. The technique may be described as follows.

(1) A glass ball is evacuated and filled with a few grams of mercury, the balling having a diameter of about two inches.

(2) Mercury vapor pervades the space in the ball.

(3) The ball is placed upon a shaft driven by a small motor and spun at various angular velocities.

(4) Since the glass ball is made of a special ultraviolet transmitting variety of glass, ultraviolet photons pour from the ball to be counted.

The ultraviolet light which is generated in the sequence described above, results from the relative motion of contiguous surfaces of mercury and glass, metal and semiconductor. The mercury remains essentially at rest while the adjacent glass surface of the ball moves at a prescribed number of revolutions per second and a corresponding linear velocity. Electrons pour from the metal to the semiconductor when the materials are in contact, equalizing the Fermi levels of the two materials. When the surfaces are separated by the motion of the glass sphere, the electrons jump back to the mercury by way of a discharge in the mercury vapor. Thus is generated ultraviolet light in the discharge.

At room temperature, the vapor pressure of mercury is of the order of 10^{-3}mm Hg, so that the mean free path is about equal to the diameter of the ball. Helium has been introduced to a pressure of 0.6 mm Hg, and the ultraviolet yield has been observed to increase by a factor of ten. A helium pressure of 2mm Hg will shortly be introduced to ascertain whether the ultraviolet yield can be further increased.

All the above listed activities are directed toward preparation of a paper to be presented in New York at the annual meeting of the American Physical Society in January of 1966.

C. E. Mandeville

RECEIVED FEB 26 1965 Engineering Experiment Station

NASA Grant NaG-692 Progress Report 24 Feb 1965

Width of the Tracks of Heavy Ions in Emulsions and Other Media, Robert Katz, Principal Investigator.

Research done on this problem before the initiation of the present grant has culminated in a paper entitled "Width of Ion and Monopole Tracks in Emulsion", by R. Katz and J.J. Butts, Phys. Rev. 137, B 198 (1965).

A new width computation has been initiated based on experimental measurement of the penetration of normally incident low energy electrons through thin films, by Kanter and Sternglass, Phys. Rev. 126, 620 (1962). This computation uses the criteria of track formation we have previously established. An emulsion grain is assumed to be sensitized when the ionization energy deposited by delta rays exceeds a threshold value characteristic of the emulsion. The new computation assumes delta rays to be ejected normal to the ion's path. Agreement obtained with experimental measurements of cosmic ray produced tracks in emulsion considerably improved over the earlier model. A preliminary report will be given at the March meeting of the American Physical Society.

These track width computations have been applied to problems of radiation damage from heavy ions, with good results. Published data on inactivation cross sections for enzymes, for phage, and for yeast obtained with different ions at several values of ion speed have been coordinated with a single constant- the threshold dosage for inactivation. This work appears to be a major forward step in understanding the hazards of heavy ion irradiations to space travellers.

Copy to: Leland Hobson
with inclosures

Kansas State University

Manhattan, Kansas 66504

Department of Physics
Physical Science Building

15 March 1965

Mr. John R. Craig III
Research Program Manager
Grants and Research Contracts
Office of Space Science and Applications
National Aeronautics and Space Administration
Washington, D. C. 20546

Dear Mr. Craig:

Ref: Sc-NsG-692/17-01-005

I inclose a xerox copy of a section of the Bulletin of the American Physical Society 1965 March Meeting.

Acknowledgement that the research was partially supported by NASA grant was inadvertently omitted from the text of abstracts KF11 and KF12, Bull. Am. Phys. Soc. II 10, 378,9 (1965).

A reprint of a paper entitled "Width of Ion and Monopole Tracks in Emulsion", Robert Katz and J.J. Butts, Phys. Rev. 137 , B198 (1965), describes work done in this laboratory prior to the grant award on the subject of the abstracts. A copy is inclosed for your information.

Sincerely yours,

Robert Katz
Professor

Reprinted from THE PHYSICAL REVIEW, Vol. 137, No. 1B, B198–B203, 11 January 1965
Printed in U. S. A.

Width of Ion and Monopole Tracks in Emulsion

ROBERT KATZ AND J. J. BUTTS
Kansas State University, Manhattan, Kansas
(Received 13 July 1964; revised manuscript received 14 September 1964)

The width of the tracks of ions in emulsion has been calculated from the assumption that a developable image is formed when the energy dosage deposited by delta rays exceeds a threshold value, here found to be 6000 ergs/cm^3 in *G*-5 emulsion. The theory agrees with measurements of track width obtained by projecting track images to a magnification of 3000× and tracing around their outline, while truncating isolated delta rays at their bases. Agreement is to within a grain diameter to a range of about 4 cm. From the theory we infer that there is no Z intelligence contained in the last 10 μ of track length, and that very poor resolution in Z (above 15) is obtained in the thin-down region (last 150 μ). The calculation has been extended to infer the width of the track of a Dirac monopole as a function of its range. The length of track required for discrimination between ions and monopoles depends on the monopole mass. Thus monopoles of mass 5 amu, unit pole strength ($137e/2$), and energy 1500 MeV will have a range of 1000 μ, and can be confused in width with ions of charge 20. On the other hand 3-amu unit-strength monopoles of 100-MeV energy will have a range of 100 μ and can be clearly distinguished from any ion. If 1 cm of track is available, any monopole (to mass 50 amu) can be clearly distinguished from all ions by the fact that its track width does not diminish with increasing range, and achieves a value of about 4 μ, in G-5 emulsion.

I. INTRODUCTION

WHEN the tracks of heavy ions were first detected in emulsion exposed to cosmic rays, in 1948, their width was thought to be proportional to ionization, and the wedge-shaped appearance of the tracks near the end of the range was attributed to electron pickup.

In 1953 Lonchamp[1] projected machine-accelerated ions into emulsion and found that it was necessary to clarify the distinction between ionization and width, for the width was decreasing at ranges where the ionization was increasing. Electron pickup occurred much too near the end of the range to be responsible for the wedge-shaped appearance of the tracks. He proposed a simple theory in which width was calculated as the diameter of a cylinder, centered on the ion's path, through whose surface 400 delta rays passed in each 100 μ of track length. By use of the delta-ray distribution formula, a range-energy relation for slow electrons, and an assumption of normal ejection of delta rays, a numerical value of track width could be computed. Though Lonchamp identified the mechanism of width formation, his formulation was not quantitative.

A substantial improvement in Lonchamp's theory was made by Bizzeti and Della Corte,[2] in 1959, by altering the track formation criterion from one of delta-ray flux to one of energy flux. At low ion energies, in the thin-down region, where delta rays emerging from the critical cylinder had a residual range less than a grain diameter, this theory was in reasonable agreement with experiment, but our extrapolation of the theory to higher ion energies yielded theoretical values for the track width which did not fit experimental data.

The present theory of track formation is built on the foundation of the work of Bizzeti and Della Corte. It assumes that charged particles transfer energy to a medium through the formation of delta rays, and that the detector is sensitized when these delta rays deposit energy in the medium at a rate exceeding a threshold dosage. In the case of emulsion, all photographic grains touching the cylinder of critical diameter are assumed to be sensitized. The track width is then the sum of the diameter of the critical cylinder, the diameter of a developed grain, and the diameter of an undeveloped grain (see Fig. 1). Processing is assumed to affect the width through the diameter of the developed grain, and possibly through the value of the threshold dosage.

Most detectors lack both the spatial resolution and the sensitivity for these detailed considerations of the mechanism of track formation to be significant. But, since electron-sensitive emulsion has both sensitivity and spatial resolution, the secondary ionization from delta rays in the tracks of heavy ions dominates the appearance of these tracks.

In the present calculation delta rays are assumed to be ejected with effective spherical symmetry, to obey a power-law "diffusion-length" energy relation, and to have an energy spectrum in accordance with the usual delta-ray distribution formula. We are forced to treat the coefficient of the power law as an adjustable parameter, for want of complete data. Similarly, the threshold dosage for emulsion sensitization is treated as an

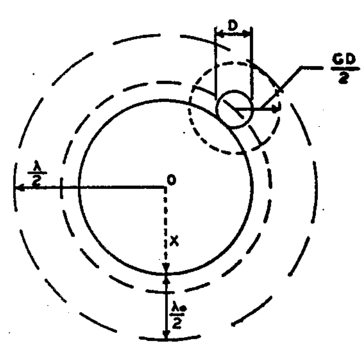

FIG. 1. Cross section of track. A grain of diameter D tangent to the critical cylinder grows in development to diameter GD. The total track width after development is $\lambda=2x+(G+1)D$.

[1] J. P. Lonchamp, J. Phys. Radium **14**, 433 (1953).
[2] P. G. Bizzeti and M. Della Corte, Nuovo Cimento **11**, 317 (1959).

adjustable parameter. The numerical values of these parameters are determined from the over-all fit of track-width data with computed curves.

Studies of the identification of the Dirac monopole in emulsion, based on the track-width theory of Lonchamp, were initiated by Katz and Parnell[3] in 1959. According to this theory the tracks of heavy ions are thin at high energy. As the energy diminishes, the tracks increase in width, passing through a maximum, and then thin down in the last several hundred microns of range. The tracks of monopoles are to be wedge shaped, being wide at high energy and thinning down continuously as they approach the end of their range without passing through a maximum. While the qualitative description of the difference between ion and monopole tracks remains intact, the quantitative details of the description of the width of ion tracks has been significantly improved in the present work, with corresponding improvement to be expected in the extrapolation to the track of a monopole. The track of a unit-pole-strength Dirac monopole will achieve and retain a width slightly greater than 4 μ in *G*-5 emulsion. This width will be achieved at ranges of approximately $70A$ μ, where A is the monopole mass in amu. The saturation width itself depends on the pole strength. Thus, *any track whose width never decreases as its range increases may be identified as a monopole.* The mass may be determined from the range at which the width reaches its saturation value, and the pole strength may be determined from the magnitude of this width.

Machine experiments to manufacture monopoles[4,5] have thus far been limited to possible masses of 3 amu. Monopoles of this mass could be readily identified, in tracks 100 μ long. For this range an energy of 100 MeV is required. This energy would be attained by a Dirac monopole in 5 cm in a field of 1 kOe.

II. THEORY OF TRACK WIDTH

The track width may be calculated by postulating that an undeveloped grain will be sensitized if any part of its volume is sufficiently close to the path of the primary particle to receive the threshold dosage for latent image formation E^*. From symmetry, all grains included in and tangent to a cylinder of radius x will be sensitized. On processing, the outermost grains will grow from diameter D to a new diameter GD, so that an examination of the geometry of Fig. 1 leads to the result that the track width λ is given by the equation

$$\lambda = 2x + \lambda_0, \tag{1}$$

where

$$\lambda_0 = (G+1)D. \tag{2}$$

At low ion energies where the range of delta rays is significantly less than a grain diameter, the minimum width achieved is λ_0, the sum of the diameters of a developed grain and an undeveloped grain. The formulation here is consistent with our observation that the track width in the first 10 μ is constant and is the same for all Z. We have observed that there are differences in λ_0 for tracks terminating at different depths in the emulsion, apparently due to processing.

If $E(x,\beta,Z)$ is the energy flux through a cylinder of radius x carried by delta rays made by an ion charge Ze and speed βc, then the energy density deposited in a shell of thickness Δx is $(E(x,\beta,Z)-E(x+\Delta x,\beta,Z))/(2\pi x\Delta x)$. In the limit of small Δx we require that this expression approach a limit E^*, an adjustable parameter, so that

$$E^* = -\frac{1}{2\pi x}\frac{\partial E(x,\beta,Z)}{\partial x}, \tag{3}$$

and we must turn to the task of calculating $E(x,\beta,Z)$.

Let $\bar{W}(x,w)$ represent the average energy carried through a cylinder of radius x by an electron of energy w, the average being with respect to the direction of emission. The total energy flux through the cylinder of unit length, is obtained by integrating $\bar{W}dn$, where dn is the number of delta rays per unit path length having energies between w and $w+dw$, produced by an ion of effective charge Ze moving with speed βc. We have

$$dn = \frac{2\pi Ne^4Z^2dw}{mc^2\beta^2w^2} = C\frac{Z^2}{\beta^2}\frac{dw}{w^2}, \tag{4}$$

where the mass of an electron and its charge are m and e, and N is the number density of electrons in the medium (emulsion) through which the ion passes. The constant C is implicitly defined in Eq. (4) as $C=2\pi Ne^4/(mc^2)$. We use observed trackwidths (corresponding to electrons of energy $w \lesssim 40$ keV) to simplify the rigorous delta-ray distribution formula which contains an additional factor of $(1-\beta^2 w/w_{\max})$. This factor is essentially $(1-w/2mc^2\gamma^2)$, or nearly 1, for this calculation. This equation must be supplemented by an expression for the effective charge Ze of an ion of atomic number Z' at speed βc in emulsion; according to Barkas[6] Ze may be expressed as

$$Ze = Z'e[1-\exp(-125\beta/Z'^{2/3})]. \tag{5}$$

Using Eq. (4) we obtain

$$\begin{aligned} E(x,\beta,Z) &= \int_{w(x)}^{w_{\max}} \bar{W}(x,w)dn \\ &= C\frac{Z^2}{\beta^2}\int_{w(x)}^{w_{\max}} \frac{\bar{W}(x,w)}{w}\frac{dw}{w}, \end{aligned} \tag{6}$$

[3] R. Katz and D. R. Parnell, Phys. Rev. 116, 236 (1959).

[4] E. Amaldi, G. Baroni, H. Bradner, H. G. deCarvalho, L. Hoffman, A. Manfredini, and G. Vanderhaeghe, CERN 63-13, Geneva, 1963 (unpublished).

[5] E. M. Purcell, G. B. Collins, T. Fujii, J. Hornbostel, and F. Turkot, Phys. Rev. 129, 2326 (1963).

[6] H. Barkas, *Nuclear Research Emulsions* (Academic Press Inc., New York, 1963), Vol. 1, Chap. 9, p. 371.

where the lower limit $w(x)$, is the energy of a delta ray whose diffusion length is just sufficient to penetrate the cylinder if it is ejected normally, and the upper energy limit $w_{max}=2mc^2\beta^2\gamma^2$, is the maximum delta-ray energy as determined by kinematics.

To complete the calculation we need a diffusion relation for low-energy electrons. Range-energy relations for electrons customarily give the maximum range or the extrapolated range expected from a population of monoenergetic electrons. The present calculation requires an average range. Since no data are available for the diffusion length at these low energies, we have altered an experimental power-law range-energy relation by treating its coefficient k as an adjustable parameter. We have

$$r=kw^{\alpha}, \tag{7}$$

where r is the diffusion length in microns, w is the electron energy in keV. The exponent is taken to be 1.72, a value suggested by Glocker[7] for energies between 1 and 100 keV.

For simplicity, delta rays are assumed to follow straight-line paths and their angular distribution is taken as effectively spherically symmetric. In the calculation a more relaxed angular distribution is actually used; that is,

$$f(\theta)+f(\pi-\theta)=1/2\pi. \tag{8}$$

The sum of the fore and aft electron-ejection probabilities is constant.

Reexpressing Eq. (7) as $w=(r/k)^{1/\alpha}$, and changing the variable in Eq. (6), we obtain

$$E(x,\beta,Z)=\frac{CZ^2}{\alpha\beta^2}\int_x^R \frac{\overline{W}(x,r)}{w(r)}\frac{dr}{r}, \tag{9}$$

where the energy w of the delta ray has been written as $w(r)$ for emphasis and where $R=k(2mc^2\beta^2\gamma^2)^{\alpha}$ is the maximum diffusion length of an electron. Bizzeti and Della Corte[2] have shown that the integral in Eq. (9) is a function of the ratio x/R only. Thus we have

$$E(x,\beta,Z)=\frac{C}{\alpha}\frac{Z^2}{\beta^2}I\left(\frac{x}{R}\right). \tag{10}$$

The track width may now be determined by applying the condition of constant dosage from Eq. (3). On writing

$$I'\left(\frac{x}{r}\right)=\frac{\partial}{\partial x}I\left(\frac{x}{R}\right),$$

replacing C by its value and rearranging, we find

$$\frac{Z}{\beta R}\left(\frac{N}{E^*}\right)^{1/2}=\left[\frac{-\alpha mc^2}{e^4}\frac{x}{R}\frac{1}{I'(x/R)}\right]^{1/2}. \tag{11}$$

We have used this equation to plot a universal curve for the calculation of track width in emulsion, or in any detector (see Fig. 2). For G-5 emulsion, $N=1.045\times10^{24}$ electrons/cm³. For best fit with our track width data we have taken the threshold sensitivity of G-5 emulsion to electrons to be 6000 ergs/cm³. Since the maximum diffusion length R is a function of β, as previously given, we may find x from the curve for given values of β and Z. To fit our data, k [Eq. (7)] was adjusted to 0.006.

Finally, accepted values of proton range[8] are used in conjunction with Heckman's formula[9] to convert β to range for heavy ions, taking electron pickup into account. The results are plotted in Fig. 3.

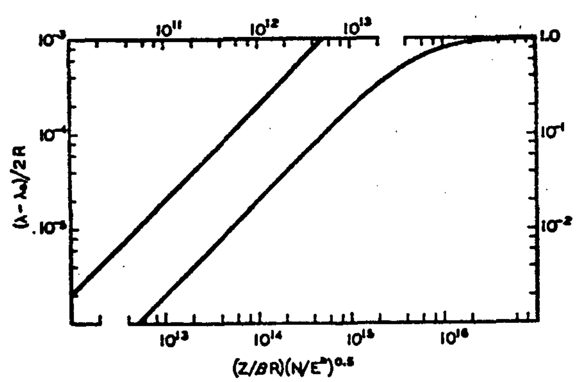

FIG. 2. Universal curve (Gaussian units) for calculating track width, λ, as a function of β for ions of charge Ze. The electron density N, the threshold dosage E^*, the maximum diffusion length of an electron R, and the sum of the developed and undeveloped grain diameters λ_0, all depend upon the emulsion.

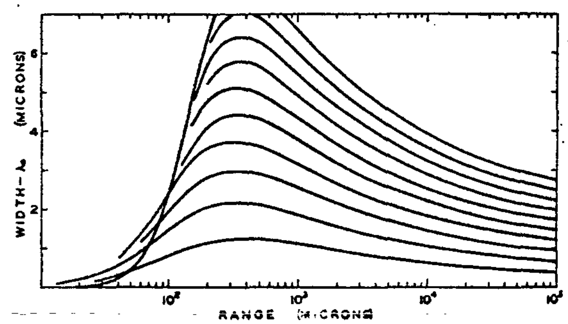

FIG. 3. Theoretical plot of reduced track width $(\lambda-\lambda_0)$ versus range for ions of $Z=5$, 10, 15, 20, 25, $\cdots$, 50. The constant λ_0 is equal to the sum of the developed and undeveloped grain diameters (approximately 0.75 μ for $G-5$ emulsion). At large ranges the width increases with Z. The mass assignment is for the most abundant isotope.

III. EXPERIMENT, AND ITS CONNECTION WITH THEORY

The track width is subject to statistical fluctuations. To find an average width comparable to the computed width, we measure the area per unit length of a segment

[7] R. Glocker, Z. Naturforsch. 3a, 129 (1948).

[8] M. M. Shapiro, in *Handbuch der Physik*, edited by S. Flügge (Springer-Verlag, Berlin, 1958), Vol. 45, p. 366.

[9] H. H. Heckman, B. L. Perkins, W. G. Simon, F. M. Smith, and W. H. Barkas, Phys. Rev. 117, 544 (1960).

of track which is long enough to smooth out the irregularities, but not so long that the average width changes appreciably in the segment. Ten-micron segments were used in the first 150 μ, and 50-μ segments were used at greater ranges.

Measurements were made by tracing around a projected image of the track, magnified 3000× by a Leitz nuclear-emulsion microscope provided with a xenon lamp. Disconnected clumps of silver were ignored and isolated delta rays were cut off at their base. The areas of the profiles traced in this manner were measured with a planimeter.

To normalize the data for variation in processing (grain size) with depth, the width of a track of 3-cm residual range was measured at different depths. Over small intervals at this large range, any width variation is due to variation of λ_0 with depth in the emulsion. Through use of these measurements, all data were normalized to a depth of 150 μ by an additive correction.

The theoretical results indicate that the tracks of all ions have the same width λ_0 in the last 10 μ of their range. This result is supported by our normalized data, and may be noted in published photographs.[10] We have found that $\lambda_0=0.75\ \mu$, in our emulsions, a value consistent with average data for G-5 emulsion given by Barkas,[6] who gives the diameter of a developed grain as 0.5 μ and the diameter of an undeveloped grain as 0.27 μ.

The combination of parameters yielding the best fit to our data are $E^*=6000$ ergs/cm^3, and $k=0.006$ [see Eq. (7)]. Our determination of k gives a diffusion length which is about one-third the maximum range of 10-keV electrons, as given by Feldman.[11]

Width measurements were made on eight tracks found in emulsion exposed to cosmic rays at an altitude of 100 000 ft. The results are shown in Figs. 4 and 5, plotted together with the theoretical curves for the best estimate of Z, and for $Z\pm Z^{1/2}$ to show discrimination. Most of the measured tracks agree with the theory to within a grain diameter (0.5 μ) at all ranges to 4 cm. In all calculations the ion mass was taken as that of the most abundant isotope.

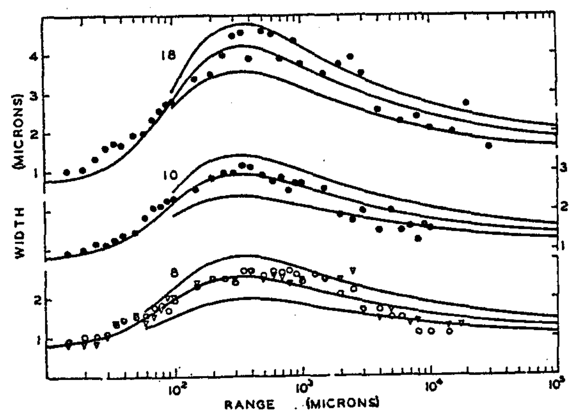

FIG. 4. Data for four tracks found in $G-5$ emulsion exposed to the cosmic rays. The families of curves represent the best fitting theoretical curve ($Z=8$, 8, 10, 18). To show Z discrimination, each assigned Z is bounded by $Z\pm Z^{1/2}$. All the data are normalized to an emulsion depth where $\lambda_0=0.75\ \mu$.

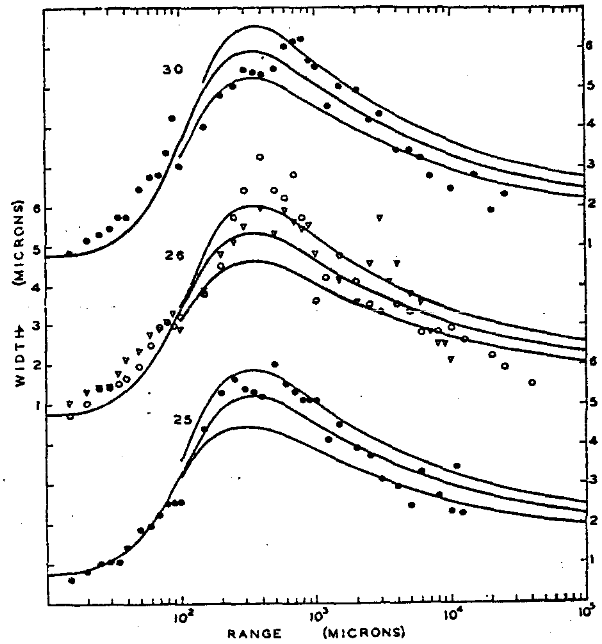

FIG. 5. Data for four tracks found in $G-5$ emulsion exposed to the cosmic rays. The families of curves represent the best fitting theoretical curve ($Z=25$, 26, 26, 30), each bounded by $Z\pm Z^{1/2}$, as in Fig. 4. All the data are normalized to an emulsion depth where $\lambda_0=0.75\ \mu$.

Comparison of the theory with published data for the width of machine accelerated ions is shown in Figs. 6 and 7, where the published data of Bizzeti and Della Corte[2] and of Skjeggestad[12] are plotted over our theoretical curves.

Data and theory show that the range at which the width of an ion track is a maximum is substantially independent of Z.

It appears that the best Z discrimination should be obtained when measurements are made near the maximum width. The roughness of the track outline in this region is offset by the slower variation of width with range (as compared to the thin-down region of the track), allowing measurement of longer segments.

The theory predicts that the width-range curves of ions of different Z cross in the thin-down region. For ranges less than 150 μ, a plot of reduced width $(\lambda-\lambda_0)$ versus Z shows a maximum (see Fig. 8). This effect is easily understood in terms of the width limitation imposed by the maximum diffusion length of delta rays. In the thin-down region the very large number of delta rays per unit track length causes the theoretical

[10] C. F. Powell, P. H. Fowler, and D. H. Perkins, *A Study of Elementary Particles by the Photographic Method* (Pergamon Press Inc., New York, 1959), pp. 170–175.

[11] C. Feldman, Phys. Rev. 117, 455 (1960).

[12] O. Skjeggestad, Nuovo Cimento 8, 927 (1958).

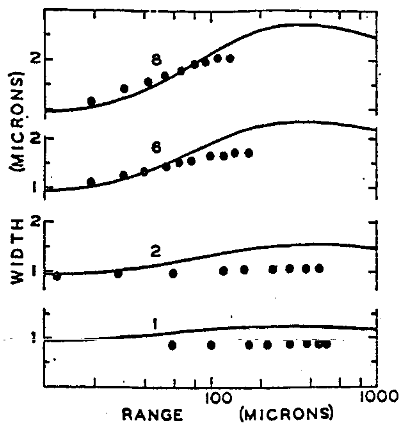

FIG. 6. Comparison of theory with published photometric track-width data of Bizzeti and Della Corte (see footnote 2) obtained with accelerated ions ($Z=1$, 2, 6, 8). $\lambda_0=0.8\,\mu$.

width to be approximately equal to the diffusion length of the electrons of maximum energy. Thus, in the thin-down region the width is almost proportional to $\beta^{2\alpha}$. At a range of, say, 50 μ, the speed of an ion of $Z=50$ is less than that of a $Z=20$ ion. This is due to electron pickup[7]: a $_{27}Co_{59}$ ion has an extra range of 120 μ and a $_{50}Sn_{120}$ ion has an extra range of 360 μ over the range otherwise predicted from proton ranges. The track of the lighter ion is therefore wider than the track of the heavier ion. These considerations imply that Z assignments based on width, or on the area of the thin-down wedge, are insensitive to Z and are ambiguous above $Z=15$. The situation is vastly improved at a range of 150 μ.

IV. WIDTH OF MONOPOLE TRACKS

A slowly moving monopole of pole strength g generates an electric field normal to the trajectory of magnitude gvb/cr^3, where r is the distance to the field point, and b is the impact parameter. We expect a monopole to interact with matter through this field. A slowly moving charge carries with it an electric field whose component normal to the trajectory is Zeb/r^3 (Gaussian units). A comparison of these fields suggests that formulas for ionization and delta-ray distribution for moving ions can be converted to formulas appropriate to monopoles by replacing Ze by $g\beta$. This recipe was derived rigorously by Bauer[13] and by Cole[14] in 1951.

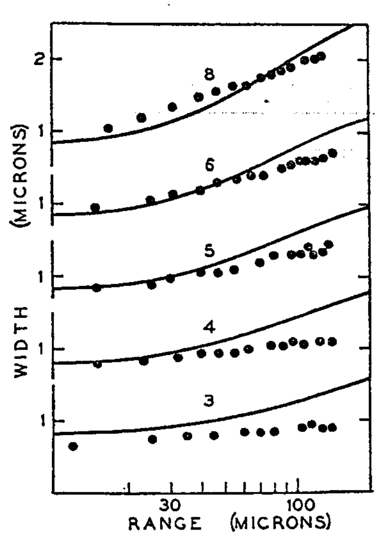

FIG. 7. Comparison of theory with published visual track-width data of Skeggestad (see footnote 9) obtained with accelerated ions ($Z=3$, 4, 5, 6, 8). $\lambda_0=0.8\,\mu$.

We may find an expression for the delta ray distribution for monopoles by making the substitution $g\beta$ for Ze in Eq. (4) to obtain

$$dn=C(g^2/e^2)(dw/w^2). \qquad (12)$$

The delta-ray distributions for charges and poles are plotted in Fig. 9. Note that the delta-ray distribution formula remains valid at high energies, because of compensating factors of γ which appear at high speeds from the Lorentz contraction and time dilation.[15] In Fig. 9, curve A is the delta-ray distribution for a Dirac monopole (the kinematic cutoff depends on β and is shown as a dashed line for $\beta=0.25$ at $W=68$ keV). The other two curves show the variation in the delta-ray distribution with β for ions of $Z=16$. It is significant that the delta-ray distribution for poles depends on β only through the changing value of the kinematic cutoff.

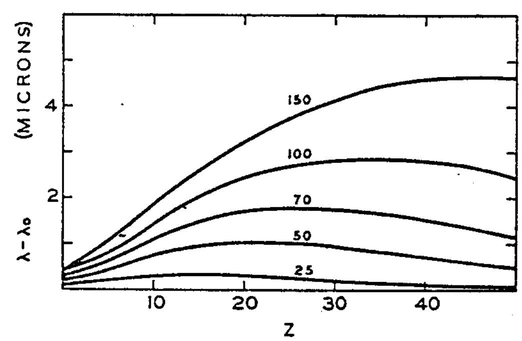

FIG. 8. Curves showing the theoretical variation of track width with Z at ranges of 25, 50, 70, 100, and 150 μ. Notice, for example, that the widest tracks at 50 μ are due to ions of charge $20e$.

An increase in β adds more delta rays of higher energy leaving the rest of the distribution unchanged. Thus, an increase in β cannot produce a decrease in track width. The width of a monopole track must increase monotonically with β, independent of the detailed mechanism by which a track-width theory converts the delta-ray distribution to track width.

A universal curve for determining monopole track width as a function of β may be obtained by making the substitution $g\beta=Ze$ in the abscissa label of Fig. 2.

To establish a range-β relation for monopoles, the ionization formula of Bethe[16] was integrated, making shell corrections according to the procedure of Vigneron.[17] The resulting range values were found to be

[13] E. Bauer, Proc. Cambridge Phil. Soc. 47, 777 (1951).
[14] H. J. D. Cole, Proc. Cambridge Phil. Soc. 47, 196 (1951).
[15] B. Rossi, *High Energy Particles* (Prentice-Hall, Inc., New York, 1952), Chap. 2, p. 18.
[16] M. S. Livingston and H. A. Bethe, Rev. Mod. Phys. 9, 245 (1937).
[17] P. L. Vigneron, J. Phys. Radium 14, 145 (1953).

in agreement with experimental data for protons of $\beta<0.9$ to within 5%.[8] The ionization formula was then converted by the usual recipe ($Ze\rightarrow g\beta$) and integrated to give range-β values for monopoles. Our calculations of monopole range were in agreement with a curve of Amaldi *et al.*[4] There is some question about the interaction of poles with the medium in the limit of low velocity, when the electric field of the moving pole drops to zero. We infer from arguments by Malkus[18] and others that a pole will interact strongly with matter when its energy is of the order of tens of electron volts, and that the range we have calculated here is within a few microns or within 5% of the true range, whichever is greater.

The results of these calculations are plotted in Fig. 10, where the reduced width ($\lambda-\lambda_0$) of the tracks of Dirac monopoles of unit strength ($137e/2$) and of twice unit strength ($137e$) is plotted against a background of track-width-range curves for ions.

The most obvious feature of the monopole track is the absence of a maximum width, a feature which is required by the delta-ray distribution relation for poles, Eq. (12), independent of other aspects of the track-width theory. The track of a monopole is strongly dependent on its mass and its magnetic charge, as shown in Fig. 10. The range at which the track reaches saturation width is determined by the mass of the monopole, while the magnitude of the saturation width is determined by the pole strength.

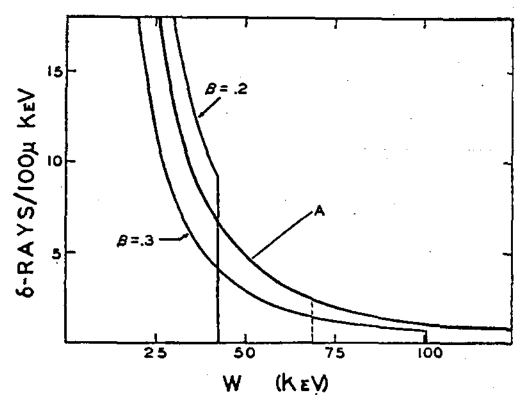

FIG. 9. The spectrum of delta rays in $G-5$ emulsion for unit Dirac monopoles (curve A), and for $Z=16$ ions at $\beta=0.2$ and 0.3. The delta-ray spectrum for poles is the same for all β, except for the position of the kinematic cutoff, shown as a dashed line at $w=68$ keV for $\beta=0.25$.

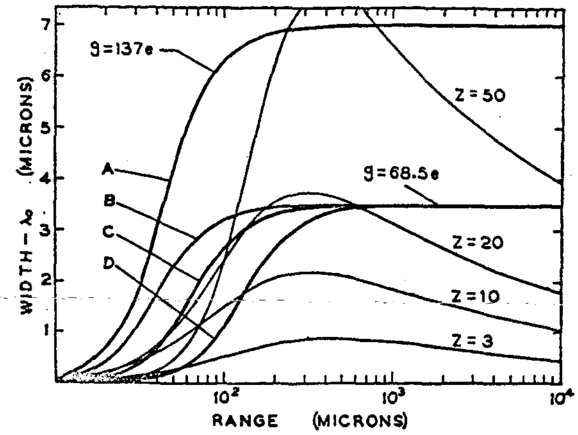

FIG. 10. Comparison of the width of tracks of ions ($Z=3$, 10, 20, 50) and monopoles of unit pole strength and twice unit pole strength in $G-5$ emulsion. The family of monopole curves (heavy lines) includes the anticipated track width for a monopole of strength $g=137e$ and $m=10$ amu (curve A), and of $g=68.5e$ with $m=3$ amu (curve B), $m=5$ amu (curve C), and $m=10$ amu (curve D).

The region of possible confusion with ions depends on the mass assumed for the monopole. For masses less than 3 amu, the largest possible mass obtainable in recent accelerator experiments,[4,5] monopoles would be easily identified if only the last 50 μ of track were available. Monopoles with mass greater than 10 amu would be clearly distinguished from ions if 500 μ of track were available for measurement. For other masses, a pole might be confused with an ion on the basis of track-width measurements to ranges of 1000 μ. For example, a 5-amu pole and a $Z=20$ ion display nearly the same range-width relation to 1000 μ.

In a recent paper Goto[19] has predicted that monopoles from cosmic space would be accelerated to energies of 10^{20} eV. Monopoles of these energies may be expected to display a constant track width of approximately 4 μ in G-5 emulsion, according to these calculations, and should be readily identifiable.

ACKNOWLEDGMENTS

We are grateful to D. E. Guss for the emulsion used in these measurements. We are also indebted to E. W. Hoffman and M. R. Querry for their help in the calculations, and especially to E. J. Kobetich for his help in measurement and machine computation.

[18] W. V. R. Malkus, Phys. Rev. 83, 899 (1951).

[19] E. Goto, Progr. Theoret. Phys. (Kyoto) 30, 700 (1963).

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rate of 0.357°/h. It is believed that crystal strain is the primary cause for explosions during growth.[2] Starting growth at a high temperature and uniformly cooling the sample sufficiently slowly anneals the crystal(s). This process has produced 20–50 crystals per sample vial with no explosions.

[1] F. F. Bowden and A. D. Yoffe, *Fast Reactions in Solids* (Butterworths Scientific Publications, London, 1958), p. 123.
[2] W. C. McCrone, Proc. Basic Contractors Conf., 9th, USAERDL (Oct. 1960), p. 7.

KF9. Positron Lifetimes in Metal–Ammonia Solutions.* L. H. Dieterman, W. E. Millett, and J. C. Thompson, *The University of Texas.*—The lifetimes of positrons have been measured in solutions of lithium in liquid ammonia with a resolution of 0.5 nsec. The metal concentration was varied from a mole ration (Li:NH_3) of 0.0003 to 0.03; measurements were also made in pure NH_3, all at −65°C. A lifetime of 1.6 nsec was found in pure NH_3 for the long component; this same component had a lifetime of 0.6 nsec in the most concentrated solution. The fraction associated with this component varied from 28% to 13% over the same range, but was concentration independent at mole ratios above 0.003. At concentrations near a mole ratio of 0.005, evidence was found for a 3rd, long-lived, component.

* Research assisted by the U. S. Office of Naval Research, the National Science Foundation, and the R. A. Welch Foundation.

KF10. Soft X-Ray Disometry for Radiation-Chemistry Studies of Hydrocarbons.* Otto H. Hill, *University of Missouri, Rolla.*—Fundamental radiation-chemistry studies dedicated to dynamic measurements of the *rates* at which particular chemical reactions are induced in a material system during exposure to a radiation field require that the radiation source be integrally mated to the analytical equipment to be employed. This may be provided by relatively low energy (<100 kV) x-ray sources. Customary reservations regarding the quality of the dosimetry available for such sources have been relieved by the design and development of homogeneous, variable plate-separation ion chambers (consisting of polyethylene bodies and utilizing ethylene as the cavity gas) to specify *absolute* energy deposition in typical hydrocarbons with an accuracy of ±7%. Specification of the energy deposition in the cavity gas, which is exempt from criticisms based upon inherent chamber inhomogeneities, is deduced from lim $\Delta I/\Delta V$ as V increases without limit, where I is the ionization current and V is the collector volume. These techniques are also exempt from criticisms based upon satisfaction of geometrical equivalence and "electronic equilibrium" in sample systems and are particularly adaptable to radiation dose specification in thin (3–15 mil) sample specimens, which are required in many analytical studies. The unique advantages provided by such sources and the associated dosimetry techniques are discussed, together with examples of dynamic analytical applications.

* Work supported at General Dynamics Corp., Fort Worth, by the U. S. Air Force Weapons laboratory.

X**KF11. Biological Effects of Heavy-Ion Irradiation.** J. J. Butts (introduced by Robert Katz) and Robert Katz, *Kansas State University.*—The relative inactivation cross sections for ions of different Z may be predicted by use of a recently developed theory of track width in emulsion.[1] The dose delivered to the material by δ-rays is calculated as a function of distance from the ion's path using the well-known δ-ray energy spectrum and an extrapolated range–energy relation for very slow electrons. The measured cross section is interpreted as the area of a cylinder of material inactivated by the passing ion and is calculated theoretically by assuming a threshold inactivation dose E^* characteristic of each biological material. Our calculations are in good agreement with relative cross sections measured by Dolphin and Hutchinson[2] for two different enzymes with $Z=1, 6, 8, 9$ at $\beta=0.145$. We have no need for such concepts as target size, overlap factor for δ-rays, energy per ion cluster, and sensitive volume of material, which are necessary in the customary associated volume calculation of Lea.[3]

[1] R. Katz and J. J. Butts, "Width of Ion and Monopole Tracks in Emulsion," Phys. Rev. (to be published).
[2] G. W. Dolphin and F. Hutchinson, Radiation Res. 13, 403 (1960).
[3] D. E. Lea, *Actions of Radiations on Living Cells* (Cambridge University Press, London, 1955).

X **KF12. Width of Ion Tracks in Emulsion.** E. J. Kobetich (introduced by R. Katz), J. J. Butts, and R. Katz, *Kansas State University.*—Experimental studies of the energy flux and electron penetration through thin films of aluminum by normally incident low-energy electrons, by Kanter and Sternglass,[1] have been applied to the calculation of the width of ion tracks in emulsion. As in the width theory of Katz and Butts,[2] it is assumed that an emulsion grain is sensitized when the ionization energy deposited by δ-rays exceeds a threshold value, characteristic of the emulsion. The present model assumes δ-rays to be ejected normal to the ion's path, and ignores the difference between electrons normally incident onto a plane slab and electrons radially ejected into a solid cylinder. In general, the new model is in agreement with results of the earlier calculation, even as to the threshold dosage for grain sensitization, but the number of adjustable parameters required for the calculation has been reduced from 3 to 1, the threshold energy. Agreement with experiment is noticeably improved.

[1] H. Kanter and E. J. Sternglass, Phys. Rev. 126, 620 (1962).
[2] R. Katz and J. J. Butts, Phys. Rev. (to be published).

KF13. Radiation Dose for Earth-Orbiting Satellites. Jane B. Blizard, *Physics, Engineering and Chemical Corporation.*—Satellite crews would accumulate ionizing radiation doses as follows: (1) continuously from cosmic rays, (2) several hours each day from the trapped belts in passage through the South American anomaly, and (3) about twice per month, on the average, from solar flares above 60° orbital inclination. Electron flux on the satellite walls will produce bremstrahlung in the cabin. A satellite with inclination between 28° and 30° would have a tolerable dose for a 3-month duty cycle at altitudes below 300 nm (nautical miles). The dose would increase 10-fold at an altitude of 350nm. High orbital inclination

Saturday, 27 March 1965 Muehle

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High-Polymer

Invited P

KG1. Electronic Charge Transport in Polymer Soli *Laboratory.* (30 min.)

KG2. Electronically Conducting Polymers. J. H. L (20 min.)

Contributed

KG3. Dielectric Crystalline Absorption in Oxidized Polyethylene. K. Yamafuji (introduced by W. P. Slichter), *Carnegie Institute of Technology,* and Y. Ishida,* *Bell Telephone Laboratories.*—The dielectric crystalline absorption in oxidized polyethylene has been measured as a function of frequency over the temperature range 20°∼100°C. The materials were prepared by oxidizing Marlex-type polyethylene in the melt under ultraviolet light. The samples were crystallized from the melt or from dilute solution. The absorption strength

Semi-Annual Report - NSG - 692

Statistical Radar Echo Analysis and Simulation
and its Application to Planetary Return

A. Theoretical Work

The subject of nonlinear acoustic simulation of radar return has been under study since September, 1964. Simple nonlinear modeling, and reduced range and Wavelength reduced surface heights modeling were worked and reported on. Some work on depolarization of an incident electromagnetic wave by a statistically rough surface was also completed in the first half of this year. Furthermore, the subject of specular areas on the moon and its surface permittivity was also part of our study.

B. Publications

The work so far has resulted in these technical publications:

(1) Already Accepted for Publication

(a) Hayre, H. S., "Lunar Specular Areas and Permittivity Estimation," I.E.E.E. Transactions Antennas and Propagation - to be published July, 1965

(b) Hayre, H. S., "Nonlinear Underwater Ultrasonic Simulation of Radar Return," I.E.E.E. Transactions, Sonics and Ultrasonics - accepted for publication

(2) Publications Under Preparation and/or Editorial Review by Technical Journals

(a) Hayre, H. S., "Depolarization and Surface Roughness"

(b) Hayre, H. S. and W. S. Shung, "Frequency Separation for Surface Dielectric Calculation in a Multifrequency Radar Return Experiment"

(3) Miscellaneous

Further study of backscattering from rough surfaces, and an analysis of planetary radar return data if and when available from J.P.L. and other NASA sources, will be carried out in the second half of this year.

Moreover, nonlinear acoustic simulation of various surfaces will also be performed.

H S Hayre

Dr. H. S. Hayre
Principal Investigator

Semiannual Report of Research Activities
Under NASA Grant No. NsG-692
("Determination of Optimum Nozzle Contours
for the Expansion of Dissociated Gas
by Methods of the Variational Calculus")

During this first six months, gratifying progress has been made toward realization of all of the primary objectives outlined in the proposal for this research.

The IBM 1401/1410 Computer has been successfully programmed so as to furnish an optimum nozzle contour, i.e., a contour providing maximum specific impulse. As mentioned in the proposal, the nozzle contour so obtained represents the solution to a 'Mayer problem' of the variational calculus. Thus the solution obtained at a given reaction rate provides the optimum nozzle contour to any artibrary finite length provided that the exit pressure of the nozzle is equal to the ambient pressure at that length. The solution is limited to a particular back pressure requirement at any length. This limitation of allowable end conditions is typical of solutions obtained for a Mayer problem.

In order to verify the optimum solution, several other nozzle contours have been investigated. Given the nozzle length and balanced pressure at the exit, the optimum nozzle has shown higher specific impulse in every case. Therefore, the validity of the optimum solution appears to be established on a numerical as well as a theoretical basis.

It has been possible to prove that the length of this optimum nozzle to any given area ratio and exit pressure is inversely proportional to the reaction rate constant which is employed in the calculations. Thus, the calculation of different optimum solutions for different reaction rates has been avoided.

Since the primary objectives of the proposed research have been completed, preparation of a report covering this phase of the investigation has already begun. This report should be completed by the first of July, 1965. Several attempts to obtain solutions to the problem with additional constraints (a secondary objective of the original proposal) have been unsuccessful. On the other hand, the possible use of reaction mechanisms different from those stipulated by Bray has been studied and appears to offer considerable promise. It is believed that this latter study is sufficiently promising to warrant an extension of the present contract. A definite proposal in this respect will be presented in the near future.

Respectfully submitted,

James M. Bowyer Jr.

James M. Bowyer, Jr.
Principal Investigator